

Chapter 3 Site Investigations

3-1. Scope

This chapter describes general guidance for site investigation methods and techniques used to obtain information in support of final site evaluation, design, construction, and instrumentation phases of a project with respect to rock foundations. Once a site (preliminary or final) has been selected, the problem usually consists of adapting all phases of the project to existing terrain and rock mass conditions. Because terrain and rock mass conditions are seldom similar between project sites, it is difficult, if not impractical, to establish standardized methodologies for site investigations. In this respect, the scope of investigation should be based on an assessment of geologic structural complexity, imposed or existing loads acting on the foundation, and to some extent the consequence should a failure occur. For example, the extent of the investigation could vary from a limited effort where the foundation rock is massive and strong to extensive and detailed where the rock mass is highly fractured and contains weak shear zones. It must be recognized, however, that, even in the former case, a certain minimum of investigation is necessary to determine that weak zones are not present in the foundation. In many cases, the extent of the required field site investigation can be judged from an assessment of preliminary site studies.

3-2. Applicable Manuals

Methods and techniques commonly used in site investigations are discussed and described in other design manuals. Two manuals of particular importance are EM 1110-1-1804 and EM 1110-1-1802. It is not the intent of this manual to duplicate material discussed in existing manuals. However, discussions provided in EM 1110-1-1804 and EM 1110-1-1802 apply to both soil and rock. In this respect, this manual will briefly summarize those methods and techniques available for investigating project sites with rock foundations.

Section I Preliminary Studies

3-3. General

Prior to implementing a detailed site investigation program, certain types of preliminary information will have been developed. The type and extent of information depends on the cost and complexity of the project. The

information is developed from a thorough survey of existing information and field reconnaissance. Information on topography, geology and potential geologic hazards, surface and ground-water hydrology, seismology, and rock mass characteristics are reviewed to determine the following:

- Adequacy of available data.
- Type and extent of additional data that will be needed.
- The need for initiating critical long-term studies, such as ground water and seismicity studies, that require advance planning and early action.
- Possible locations and type of geologic features that might control the design of project features.

3-4. Map Studies

Various types of published maps can provide an excellent source of geologic information to develop the regional geology and geological models of potential or final sites. The types of available maps and their uses are described by Thompson (1979) and summarized in EM 1110-1-1804. EM 1110-1-1804 also provides sources for obtaining published maps.

3-5. Other Sources of Information

Geotechnical information and data pertinent to the project can frequently be obtained from a careful search of federal, state, or local governments as well as private industry in the vicinity. Consultation with private geotechnical engineering firms, mining companies, well drilling and development companies and state and private university staff can sometimes provide a wealth of information. EM 1110-1-1804 provides a detailed listing of potential sources of information.

3-6. Field Reconnaissance

After a complete review of available geotechnical data, a geologic field reconnaissance should be made to gather information that can be obtained without subsurface exploration. The primary objective of this initial field reconnaissance is to, insofar as possible, confirm, correct or expand geologic and hydrologic information collected from preliminary office studies. If rock outcrops are present, the initial field reconnaissance offers an opportunity to collect preliminary information on rock mass conditions that might influence the design and construction of

project features. Notation should be made of the strike and dip of major joint sets, joint spacing, joint conditions (i.e. weathering, joint wall roughness, joint tightness, joint infillings, and shear zones), and joint continuity. EM 1110-1-1804, Murphy (1985), and Chapter 4 of this manual provide guidance as to special geologic features as well as hydrologic and cultural features which should also be noted.

Section II Field Investigations

3-7. General

This section briefly discusses those considerations necessary for completion of a successful field investigation program. The majorities of these considerations are discussed in detail in EM 1110-1-1804 and in Chapter 4 of this manual. In this respect, the minimum components that should be considered include geologic mapping, geophysical exploration, borings, exploratory excavations, and insitu testing. The focus of geologic data to be obtained will evolve as site characteristics are ascertained.

3-8. Geologic Mapping

In general, geologic mapping progresses from the preliminary studies phase with collection of existing maps and information to detailed site-specific construction mapping. Types of maps progress from areal mapping to site mapping to construction (foundation specific) mapping.

a. Areal mapping. An areal map should consist of sufficient area to include the project site(s) as well as the surrounding area that could influence or could be influenced by the project. The area and the degree of detail mapped can vary widely depending on the type and size of project and on the geologic conditions. Geologic features and information of importance to rock foundations that are to be mapped include:

- (1) Faults, joints, shear zones, stratigraphy.
- (2) Ground-water levels, springs, surface water or other evidence of the ground-water regime.
- (3) Potential cavities due to karstic formations, mines, and tunnels.
- (4) Potential problem rocks subject to dissolving, swelling, shrinking, and/or erosion.
- (5) Potential rock slope instability.

(6) Gas, water, and sewer pipe lines as well as other utilities.

b. Site mapping. Site maps should be large-scaled with detailed geologic information of specific sites of interest within the project area to include proposed structure areas. Detailed description of the geologic features of existing rock foundation materials and overburden materials is essential in site mapping and subsequent explorations. The determination and description of the subsurface features must involve the coordinated and cooperative efforts of all geotechnical professionals responsible for the project design and construction.

c. Construction mapping. During construction, it is essential to map the "as built" geologic foundation conditions as accurately as possible. The final mapping is usually accomplished after the foundation has been cleaned up and just prior to the placement of concrete or backfill. Accurate location of foundation details is necessary. Permanent and easily identified planes of reference should be used. The system of measurement should tie to, or incorporate, any new or existing structure resting on the rock foundation. Foundation mapping should also include a comprehensive photographic record. A foundation map and photographic record will be made for the entire rock foundation and will be incorporated into the foundation report (ER 1110-1-1801). These maps and photographs have proved to be valuable where there were contractor claims, where future modifications to the project became necessary, or where correction of a malfunction or distress of the operational structure requires detailed knowledge of foundation conditions.

3-9. Geophysical Explorations

Geophysical techniques consist of making indirect measurements on the ground surface, or in boreholes, to obtain generalized subsurface information. Geologic information is obtained through analysis or interpretation of these measurements. Boreholes or other subsurface explorations are needed for reference and control when geophysical methods are used. Geophysical explorations are of greatest value when performed early in the field exploration program in combination with limited subsurface explorations. The explorations are appropriate for a rapid, though approximate, location and correlation of geologic features such as stratigraphy, lithology, discontinuities, ground water, and for the in-situ measurement of dynamic elastic moduli and rock densities. The cost of geophysical explorations is generally low compared with the cost of core borings or test pits, and considerable savings may be realized by judicious use of these

methods. The application, advantages, and limitations of selected geophysical methods are summarized in EM 1110-1-1804. EM 1110-1-1802 provides detailed guidance on the use and interpretation of surface and subsurface methods.

3-10. Borings

Borings, in most cases, provide the only viable exploratory tool that directly reveals geologic evidence of the subsurface site conditions. In addition to exploring geologic stratigraphy and structure, borings are necessary to obtain samples for laboratory engineering property tests. Borings are also frequently made for other uses to include collection of ground-water data, perform in-situ tests, install instruments, and explore the condition of existing structures. Boring methods, techniques, and applications are described in EM 1110-1-1804 and EM 1110-2-1907. Of the various boring methods, rock core borings are the most useful in rock foundation investigations.

a. Rock core boring. Rock core boring is the process in which diamond or other types of core drill bits are used to drill exploratory holes and retrieve rock core. If properly performed, rock core can provide an almost continuous column of rock that reflects actual rock mass conditions. Good rock core retrieval with a minimum of disturbance requires the expertise of an experienced drill crew.

(1) Standard sizes and notations of diamond core drill bits are summarized in EM 1110-1-1804. Core bits that produce 2.0 inch (nominal) diameter core (i.e., NW or NQ bit sizes) are satisfactory for most exploration work in good rock as well as provide sufficient size samples for most rock index tests such as unconfined compression, density, and petrographic analysis. However, the use of larger diameter core bits ranging from 4.0 to 6.0 inches (nominal) in diameter are frequently required to produce good core in soft, weak and/or fractured strata. The larger diameter cores are also more desirable for samples from which rock strength test specimens are prepared; particularly strengths of natural discontinuities.

(2) While the majorities of rock core borings are drilled vertically, inclined borings and in some cases oriented cores are required to adequately define stratification and jointing. Inclined borings should be used to investigate steeply inclined jointing in abutments and valley sections for dams, along spillway and tunnel alignments, and in foundations of all structures. In near vertical bedding, inclined borings can be used to reduce the total number of borings needed to obtain core samples of

all strata. Where precise geological structure is required from core samples, techniques involving oriented cores are sometimes employed. In these procedures, the core is scribed or engraved with a special drilling tool so that its orientation is preserved. In this manner, both the dip and strike of any joint, bedding plane, or other planar surface can be ascertained.

(3) The number of borings and the depths to which bore holes should be advanced are dependent upon the subsurface geological conditions, the project site areas, types of projects and structural features. Where rock mass conditions are known to be massive and of excellent quality, the number and depth of boring can be minimal. Where the foundation rock is suspected to be highly variable and weak, such as karstic limestone or sedimentary rock containing weak and compressible seams, one or more boring for each major load bearing foundation element may be required. In cases where structural loads may cause excessive deformation, at least one of the boreholes should be extended to a depth equivalent to an elevation where the structure imposed stress acting within the foundation material is no more than 10 percent of the maximum stress applied by the foundation. Techniques for estimating structure induced stresses with depth are discussed in Chapter 5 of this manual.

(4) Core logging and appropriate descriptors describing the rock provide a permanent record of the rock mass conditions. Core logging procedures and appropriate rock descriptors are discussed in EM 1110-1-1804, ER 1110-1-1802, Murphy (1985), and Chapter 4 of this manual. Examples of core logs are provided in Appendix D of EM 1110-1-1804. A color photographic record of all core samples should be made in accordance with ER 1110-1-1802.

(5) The sidewalls of the borehole from which the core has been extracted offer a unique picture of the subsurface where all structural features of the rock formation are still in their original position. This view of the rock can be important when portions of rock core have been lost during the drilling operation, particularly weak seam fillers, and when the true dip and strike of the structural features are required. Borehole viewing and photography equipment include borescopes, photographic cameras, TV cameras, sonic imagery loggers, caliper loggers, and alignment survey devices. EP 1110-1-10 provides detailed information on TV and photographic systems, borescope, and televiewer. Sonic imagery and caliper loggers are discussed in detail in EM 1110-1-1802. General discussions of borehole examination techniques are also provided in EM 1110-1-1804.

b. Large-diameter borings. Large-diameter borings, 2 feet or more in diameter, are not frequently used. However, their use permits direct examination of the sidewalls of the boring or shaft and provides access for obtaining high-quality undisturbed samples. These advantages are often the principal justification for large-diameter borings. Direct inspection of the sidewalls may reveal details, such as thin weak layers or old shear planes, that may not be detected by continuous undisturbed sampling. Augers are normally used in soils and soft rock, and percussion drills, roller bits, or the calyx method are used in hard rock.

3-11. Exploratory Excavations

Test pits, test trenches, and exploratory tunnels provide access for larger-scaled observations of rock mass character, for determining top of rock profile in highly weathered rock/soil interfaces, and for some in-situ tests which cannot be executed in a smaller borehole.

a. Test pits and trenches. In weak or highly fractured rock, test pits and trenches can be constructed quickly and economically by surface-type excavation equipment. Final excavation to grade where samples are to be obtained or in-situ tests performed must be done carefully. Test pits and trenches are generally used only above the ground-water level. Exploratory trench excavations are often used in fault evaluation studies. An extension of a bedrock fault into much younger overburden materials exposed by trenching is usually considered proof of recent fault activity.

b. Exploratory tunnels. Exploratory tunnels/adits permit detailed examination of the composition and geometry of rock structures such as joints, fractures, faults, shear zones, and solution channels. They are commonly used to explore conditions at the locations of large underground excavations and the foundations and abutments of large dam projects. They are particularly appropriate in defining the extent of marginal strength rock or adverse rock structure suspected from surface mapping and boring information. For major projects where high-intensity loads will be transmitted to foundations or abutments, tunnels/adits afford the only practical means for testing in-place rock at locations and in directions corresponding to the structure loading. The detailed geology of exploratory tunnels, regardless of their purpose, should be mapped carefully. The cost of obtaining an accurate and reliable geologic map of a tunnel is usually insignificant compared with the cost of the tunnel. The geologic information gained from such mapping provides a very useful additional dimension to interpretations of rock structure deduced from other sources. A complete picture of the

site geology can be achieved only when the geologic data and interpretations from surface mapping, borings, and pilot tunnels are combined and well correlated. When exploratory tunnels are strategically located, they can often be incorporated into the permanent structure. Exploratory tunnels can be used for drainage and postconstruction observations to determine seepage quantities and to confirm certain design assumptions. On some projects, exploratory tunnels may be used for permanent access or for utility conduits.

3-12. In-Situ Testing

In-situ tests are often the best means for determining the engineering properties of subsurface materials and, in some cases, may be the only way to obtain meaningful results. Table 3-1 lists in-situ tests and their purposes. In-situ rock tests are performed to determine in-situ stresses and deformation properties of the jointed rock mass, shear strength of jointed rock mass or critically weak seams within the rock mass, residual stresses within the rock mass, anchor capacities, and rock mass permeability. Large-scaled in-situ tests tend to average out the effect of complex interactions. In-situ tests in rock are frequently expensive and should be reserved for projects with large, concentrated loads. Well-conducted tests may be useful in reducing overly conservative assumptions. Such tests should be located in the same general area as a proposed structure and test loading should be applied in the same direction as the proposed structural loading. In-situ tests are discussed in greater detail in EM 1110-1-1804, the Rock Testing Handbook, and in Chapter 5 of this manual.

Section III

Laboratory Testing

3-13. General

Laboratory tests are usually performed in addition to and after field observations and tests. These tests serve to determine index values for identification and correlation, further refining the geologic model of the site and they provide values for engineering properties of the rock used in the analysis and design of foundations and cut slopes.

3-14. Selection of Samples and Tests

The selection of samples and the number and type of tests are influenced by local subsurface conditions and the size and type of structure. Prior to any laboratory testing, rock cores should have been visually classified and logged.

Table 3-1
Summary of Purpose and Type of In-Situ Tests for Rock

Purpose of Test	Type of Test
Strength	Field Vane Shear ¹ Direct Shear Pressuremeter ² Uniaxial Compressive ² Borehole Jacking ²
Bearing Capacity	Plate Bearing ¹ Standard Penetration ¹
Stress Conditions	Hydraulic Fracturing Pressuremeter Overcoring Flat Jack Uniaxial (Tunnel) Jacking ² Chamber (Gallery) Pressure ²
Mass Deformability	Geophysical (Refraction) ³ Pressuremeter or Dilatometer Plate Bearing Uniaxial (Tunnel) Jacking ² Borehole Jacking ² Chamber (Gallery) Pressure ²
Anchor Capacity	Anchor/Rockbolt Loading
Rock Mass Permeability	Constant Head Rising or Falling Head Well Slug Pumping Pressure Injection

Notes:

1. Primarily for clay shales, badly decomposed, or moderately soft rocks, and rock with soft seams.
2. Less frequently used.
3. Dynamic deformability.

Selection of samples and the type and number of tests can best be accomplished after development of the geologic model using results of field observations and examination of rock cores, together with other geotechnical data obtained from earlier preliminary investigations. The geologic model, in the form of profiles and sections, will change as the level of testing and the number of tests progresses. Testing requirements are also likely to change as more data become available and are reviewed for

project needs. The selection of samples and type of test according to required use of the test results and geological condition is discussed in Chapter 4 of this manual. Additional guidance can be found in EM 1110-2-1902, TM 5-818-1, EM 1110-2-2909, EM 1110-1-1804, Nicholson (1983), Goodman (1976), and Hoek and Bray (1974).

3-15. Laboratory Tests

Table 3-2 summarizes laboratory tests according to purpose and type. The tests listed are the types more commonly performed for input to rock foundation analyses and design process. Details and procedures for individual test types are provided in the Rock Testing Handbook. Laboratory rock testing is discussed in Chapter 4 of this manual and in EM 1110-1-1804.

Table 3-2
Summary of Purpose and Type of In-Situ Tests for Rock

Purpose of Test	Type of Test
Strength	Uniaxial Compression Direct Shear Triaxial Compression Direct Tension Brazilian Split Point Load ¹
Deformability	Uniaxial Compression Triaxial Compress Swell Creep
Permeability	Gas Permeability
Characterization	Water Content Porosity Density (Unit Weight) Specific Gravity Absorption Rebound Sonic Velocities Abrasion Resistance

Notes:

1. Point load tests are also frequently performed in the field.